Physiological indexes associated with aerobic performance in endurance runners: effects of race duration

Benedito Sérgio Denadai[1], Marcelo Janini Ortiz[1] and Marco Túlio de Mello[2]

ABSTRACT

The aim of this study was to assess the validity of the maximal oxygen uptake ($\dot{V}O_2max$), the velocity at $\dot{V}O_2max$ ($v\dot{V}O_2max$), time to exhaustion at $v\dot{V}O_2max$ (TE), running economy (RE) and anaerobic threshold (AT) to predict the aerobic performance of the endurance athletes. Fourteen well-trained long-distance runners (33.4 ± 4.4 yr.; 62.7 ± 4.3 kg; 166.1 ± 5.0 cm; $\dot{V}O_2max$ = 60.4 ± 5.9 ml.kg^{-1}.min^{-1}) underwent the following tests: a) simulated competitions in the distances of 1,500 and 5,000 m and; b) laboratory treadmill tests to determine their $\dot{V}O_2max$, $v\dot{V}O_2max$, TE, RE and AT. The velocities (km/h) at $v\dot{V}O_2max$ (18.7 ± 0.8), AT (17.3 ± 1.1) v1,500 m (19.9 ± 0.8) and v5,000 m (17.9 ± 0.9) were significantly different. A stepwise multiple-regression analysis revealed that AT alone was the best single predictor of v-5,000 m and explained 50% of the variability in 5,000 m running velocity. For v1,500 m, TE and $v\dot{V}O_2max$ explained 88% of the variability of the performance. We conclude that, in a group of well-trained long-distance runners, the validity of the physiological indexes ($\dot{V}O_2max$, $v\dot{V}O_2max$, TE, RE e AT) to predict the aerobic performance is dependent on the distance (1,500 x 5,000 m) analyzed.

Key words: Maximal oxygen uptake. Anaerobic threshold. Running. Aerobic performance.

INTRODUCTION

The identification of physiological indexes to be used for the performance prediction presents at least two important applications in the assessment and sportive training area. The first one is that individuals with some characteristics that potentially will present higher yield in some sports may be selected. The other is that the physical training with regard to the overload application (intensity x volume) can be planned and executed according to the modality's demand, especially in relation to its metabolic aspects (powers and aerobic and anaerobic capacities). The most studied indexes to predict the aerobic performance during running are: maximal oxygen uptake ($\dot{V}O_2max$), the velocity at $\dot{V}O_2max$ ($v\dot{V}O_2max$), running economy (RE) and the indexes associated to the lactate response during submaximal exercise [lactate threshold (LT), anaerobic threshold (AT), intensity of maximal lactate steady state (MLSS)][1,2].

The $\dot{V}O_2max$ is the physiological index that best represents the aerobic power, in other words, it is a measure of the maximal energy amount that may be produced by the aerobic metabolism in a given time unit[3]. However, as the RE (oxygen expenditure for a given submaximal running velocity) may vary in up to 15% even among well-trained runners, the $v\dot{V}O_2max$ may be very different among athletes who present similar values of $\dot{V}O_2max$[4]. However, the aerobic capacity that theoretically indicates the total energy amount that could be provided by the aerobic metabolism may be well estimated through the indexes associated to the lactate response during submaximal exercise[3,5].

There are many studies in literature that analyzed that aerobic performance prediction during running from physiological indexes previously mentioned. However, these studies, using multiple or simple regression models, analyzed the relations between the physiological indexes and the aerobic performance in a single distance in the group of athletes (frequently between 1,500 and 10,000 m)[6-8]. Based on these studies, it has been proposed that the competition distance and consequently the exercise intensity may influence the relations between the physiological indexes and the aerobic yield. Nevertheless, no studies relating the aerobic performance obtained for the same athletes in different distances with two or more physiological indexes were found, especially studies using $v\dot{V}O_2max$ and its respective time to exhaustion (TE). As the aerobic contribution percentile (85% x 95%) and the relative intensity at $v\dot{V}O_2max$ (~ 105% x 95%) are proportionally very different between competitions of 1,500 and 5,000 m[9] respectively, our hypothesis is that the relations between the physiological indexes and the performance at these distances may be different. Thus, the objective of this study was to analyze the predictive validity of $\dot{V}O_2max$, $v\dot{V}O_2max$, TE, RE and AT for the performance of endurance athletes at distances of 1,500 and 5,000 m.

MATERIAL AND METHODS

Subjects

Fourteen well-trained long-distance runners (33.4 ± 4.4 yr.; 62.7 ± 4.3 kg; 166.1 ± 5.0 cm; 6.3 ± 2.9% body fat and 7.2 ± 4.9 years of training) participated in this study. All runners trained 6 days a week with weekly volume that ranged from 70 to 90 km during the specific preparation period. The study was approved by the Ethics Committee of the institution and all participants were informed of the procedures of the experiment and their implications (risks and benefits) by signing the consent form.

Experimental design

At the beginning of the experiment, all participants were accomplishing the 4th week of the training specific preparation period.

Initially, the athletes performed the simulated competitions in the distances of 1,500 and 5,000 m. In the next week, the laboratorial tests took place for the determination of $\dot{V}O_2max$, $v\dot{V}O_2max$, AT, RE and TE performed at $v\dot{V}O_2max$. An interval of at least 48 hours was determined between each test, in which each runner was oriented to perform only one low-intensity train for a maximal period of 30-40 minutes was respected.

Anthropometrical measures

The body mass was measured in a balance with precision of 0.1 kg (*Filizola*, São Paulo, Brazil). The height was measured in stadiometer placed at the own scale with precision of 0.5 cm. The body fat percentile was estimated from skin folds (tricipital, suprailiac

1. Human Performance Evaluation Laboratory – Unesp, Rio Claro, SP.
2. Exercise and Psychobiology Studies Center – EPM – Unifesp, SP.
Support: CNPq and Fapesp
Received in 24/2/04. 2nd version received in 11/8/04. Approved in 14/8/04.
Correspondence to: B.S. Denadai, Laboratório de Avaliação da Performance Humana, IB-Unesp, Av. 24A, 1.515, Bela Vista – 13506-900 – Rio Claro, SP, Brazil. E-mail: bdenadai@rc.unesp.br

and abdominal) taken at the right side of the body (Cescorf, Porto Alegre, Brazil), as described by Guedes[10].

Determination of $\dot{V}O_2max$, $v\dot{V}O_2max$ and AT

The $\dot{V}O_2max$, $v\dot{V}O_2max$ and AT were determined from treadmill incremental test (*Life Fitness 9800*, Schiller Park, IL, USA) with initial velocity of 12 km/h and increments of 1 km/h each 3 minutes until volunteer exhaustion. A pause of 30 seconds was given between each stage for the collection of 25 μl of blood from the earlobe. The treadmill inclination was maintained fixed in 1%, once this condition reflects more precisely the outdoor running energetic expenditure[11].

During tests, the exhaled gases were evaluated in the breathing-breathing mode (*Sensor Medics* – MMC, Anaheim, CA, USA) with recordings each 10 seconds. The highest average of 2 consecutive values recorded each 10 seconds we call as $\dot{V}O_2max$. The $v\dot{V}O_2max$ was the lowest velocity in which the $\dot{V}O_2max$ was reached and maintained for at least 1 minute. If $\dot{V}O_2max$ was reached during a stage and not maintained for 1 minute, the velocity of the preceding stage was considered as the $v\dot{V}O_2max$[12].

The blood lactate was determined through an electrochemical method (*YSI 2300 STAT*, Yellow Springs, OH, USA), and the AT was identified as the velocity corresponding to a fixed concentration of 3.5 mM[13].

Test to determine running economy (RE) and time to exhaustion (TE)

The runners performed a warm-up exercise for 7 min at 12 km/h followed by a rest period of 3 min. Later they ran for more 8 minutes at 14 km/h. The oxygen uptake ($\dot{V}O_2$) was measured between the 6th and 7th minutes at 14 km/h serving as reference for the athlete's RE, which was defined as the relation between the $\dot{V}O_2$ and the running velocity[14].

Shortly after the 8th minute of submaximal running in a period of 30 to 45 minutes, the treadmill velocity was adjusted to intensity corresponding to 100% of the $v\dot{V}O_2max$, initiating the running until volunteer exhaustion (TE). Studies have demonstrated the validity of TE for the assessment of the anaerobic capacity[15].

Statistical analysis

The data are expressed as average ± standard deviation (SD). The correlations between the time of competition at 1,500 and 5,000 m and the $\dot{V}O_2max$, $v\dot{V}O_2max$, TE, AT and RE were performed through step-wise multiple regression analysis. In all tests, the level of significance of $p \leq 0.05$ was adopted.

RESULTS

The $\dot{V}O_2max$, $v\dot{V}O_2max$, AT, TE and RE values of endurance runners are expressed in table 1. Table 2 shows the average velocities maintained at 1,500 and 5,000 m, expressed as absolute values (km/h) and as percentiles of the $v\dot{V}O_2max$ (%$v\dot{V}O_2max$) and AT (%AT). The velocity at 1,500 m (19.9 ± 0.8 km/h) was above the AT (17.3 ± 1.1 km/h) and above $v\dot{V}O_2max$ (18.70 ± 0.8 km/h) corresponding in average to 115.4 ± 5.8% and 106.7 ± 3.21% of these velocities, respectively. At distance of 5,000 m, the average velocity was between AT (103.6 ± 3.6%) and $v\dot{V}O_2max$ (95.9 ± 3.6%).

The only performance predictor at 5,000 m selected through the step-wise multiple regression analysis was the AT ($R^2 = 0.50$, $p < 0.05$). For 1,500 m, the TE and the $v\dot{V}O_2max$ explained 88% of the performance variability (table 3).

TABLE 1
Average values ± SD of the maximal oxygen uptake ($\dot{V}O_2max$) of the minimal velocity in which $\dot{V}O_2max$ occurred ($v\dot{V}O_2max$) and its respective time to exhaustion (TE), anaerobic threshold (AT), running economy (ER) and time obtained at 1,500 m and 5,000 m. N = 14

	$\dot{V}O_2max$ (ml/kg/min)	$v\dot{V}O_2max$ (km/h)	TE (s)	ER (ml/kg/min)	AN (km/h)	1,500 (s)	5,000 (s)
X	60.4	18.70	381.7	37.4	17.3	270.9	1,006.1
DP	5.9	0.8	152.6	3.0	1.1	11.0	54.0

TABLE 2
Average values ± SD of the minimal velocity in which $\dot{V}O_2max$ occurred ($v\dot{V}O_2max$), anaerobic threshold (AT), average velocity maintained at 1,500 m and 5,000 m, expressed as absolute values and as percentiles of (%$v\dot{V}O_2max$) and AT (%AT). N = 14

	km/h	% $v\dot{V}O_2max$	%AT
$v\dot{V}O_2max$	18.70 ± 0.8	–	–
AT	17.3 ± 1.1	92.6 ± 4.1	–
1,500 m	19.9 ± 0.8	106.7 ± 3.21	115.4 ± 5.8
5,000 m	17.9 ± 0.9	95.9 ± 3.6	103.6 ± 3.6

TABLE 3
Multiple correlation coefficients of the physiological indexes with competition time at distances of 1,500 m and 5,000 m. N = 14

Distance	Independent variables	R^2
1,500 m	$v\dot{V}O_2max$	0.64
	TE	0.88
5,000 m	AT	0.50

$v\dot{V}O_2max$ = velocity corresponding to maximal oxygen uptake; TE – time to exhaustion at $v\dot{V}O_2max$; AT – anaerobic threshold.

DISCUSSION

The main finding of this study is that the performance prediction of endurance athletes from $\dot{V}O_2max$, $v\dot{V}O_2max$, TE, RE and AT is dependent on the competition distance (1,500 x 5,000 m), even though the aerobic metabolism is predominant in these competitions. Our results are in agreement with Billat *et al.*[8] who verified that the TE and the $v\dot{V}O_2max$ explained 95% of the performance variation at 1,500 m and with data from Grant *et al.*[16], who found that the lactate response (LT) was the performance predictor at 3,000 m.

The first aspect that must be mentioned before the discussion on the meaning of our results is the relative contribution of the aerobic and anaerobic systems for the distances analyzed in this study. Although there are criticisms about the validity of the methods that estimate the contribution of different energetic systems during maximal and supramaximal exercise (> $v\dot{V}O_2max$), recent studies have verified that the aerobic contribution at 1,500 m is above 84%[17], exceeding 95% at distance of 5,000 m[9]. Even if the anaerobic contribution at 1,500 m is significant, a wide aerobic predominance is verified in distances analyzed in our study. Other aspect to be considered is the proportions between the competition average velocity and the intensities corresponding to $\dot{V}O_2max$ and AT. Our results are in agreement with the hyperbolic relation between the running velocity and its respective time to exhaustion (TE) described by many authors[18,19]. For instance, the average velocity at 1,500 m (19.9 km/h – effort time of 4.5 min) is higher (106%) than the $v\dot{V}O_2max$ (18.7 km/h – TE de 6.3 min). However, the average velocity at 5,000 m (17.9 km/h – effort time of 16.7 min) is lower than the $v\dot{V}O_2max$ (95%) and higher than the AT (103%). In our study, the TE at AT velocity was not determined, however, very recently, Billat *et al.*[20] verified TE of 44 min MLSS intensity, which is very similar to AT.

Although the $\dot{V}O_2max$ in runners (60 to 85 $ml.kg^{-1}.min^{-1}$) may be 1.5 to 2.0 times higher if compared to individuals apparently healthy, this index does not seem to be a good performance predictor when homogeneous groups of athletes are analyzed[1]. This behavior was also observed in our study, where the $\dot{V}O_2max$ did not explain significantly the performance variation in none of the distances analyzed. Initially, the low correlation between $\dot{V}O_2max$ and the aerobic performance may be explained due to the low $\dot{V}O_2max$ sensibility in well-trained athletes to the training effects. In these individuals, although important adaptations (metabolic and neuromuscular) that could determine improvements on the aerobic performance still exist, the oxygen central offer, or more particularly, the maximal cardiac debt, does not allow that the $\dot{V}O_2max$ to increase in function of adaptations caused by training. In these conditions, both the exercise lactate response and the RE, depending on the type of training, may be improved with no modifications on the $\dot{V}O_2max$[12,21]. This hypothesis is based on studies that verified increase[22] or decrease in the aerobic[23] performance with no $\dot{V}O_2max$ modifications.

Based on studies that analyzed the aerobic performance prediction from multiple or simple regression models, it has been speculated that the competition distance and consequently the exercise intensity may influence the relation between physiological indexes and yield. The data from our study supports this hypothesis. At 1,500 m, the TE (an anaerobic capacity indicator)[15] and the $v\dot{V}O_2max$ explained 88% of the performance variation. In the same way, Billat *et al.*[8] verified that the TE and the $v\dot{V}O_2max$ explained 95% of the performance variation at 1,500 m in a group of middle-distance elite runners. Thus, it verifies that the performance at 1,500 m seems to depend mainly on the anaerobic capacity (TE) and on the aerobic power, however, the anaerobic power associated to RE, i.e., the $v\dot{V}O_2max$. Thus, it is suggested that the evaluation aiming at the selection and/or the follow-up of the training effects of middle-distance athletes (800, 1,500 m) should include the determination of TE and $v\dot{V}O_2max$. With regard to the type of training, it is recommended the inclusion of 1 to 2 weekly sessions of high-intensity aerobic training with intervals (100-110% $v\dot{V}O_2max$)[21] or 2 sessions of resistance training[24], that, although do not modify the athletes' $\dot{V}O_2max$, increase the $v\dot{V}O_2max$ through the improvement of RE.

For 5,000 m, the only predictor selected through the multiple regression analysis was the AT, which explained 50% of the performance variation. These data are similar to data obtained by Grant *et al.*[16], who found that the lactate response (LT) was the only performance predictor at 3,000 m (87% of explanation) in a group of middle- and long-distance runners. Although in the study of Grant *et al.*[16] the distance had been longer, the competition average velocity was also low (95%) of the $v\dot{V}O_2max$ of its athletes. Thus, when the competition duration determines intensity below $v\dot{V}O_2max$, the performance seems to depend more on the aerobic capacity (lactate response) than on the aerobic power, even when associated to RE ($v\dot{V}O_2max$). However, our study emphasizes that the explanation coefficient was smaller than that observed in the study of Grant *et al.*[16]. Part of this difference may be explained by the performance homogeneity at 5,000 m of our group (variation coefficient = 5%) in relation to the previous study, where the performance variation at 3,000 m was higher (variation coefficient = 8%). The limitation of the utilization of a fixed concentration to determine the lactate response must also be considered in our study. It is possible that the direct determination of MLSS could present higher performance explanation levels, once the identification takes into account the lactate individual kinetics of each athlete. The MLSS has been considered as the standard method for the determination of the lactate response and, consequently, the aerobic capacity[25]. The disadvantage is that its determination requires from 3 to 4 constant-load exercise sessions with duration of approximately 30 minutes performed preferentially at different days. Therefore, the evaluation aiming at the selection and/or the follow-up of the training effects in long-distance athletes should include the determination of the lactate response, especially the MLSS. With regard to the type of raining, the inclusion of 1 to 2 weekly sessions of continuous (95-100% MLSS) or with intervals (100-105% MLSS)[9] aerobic trains are recommended particularly in the specific period.

Based on our results, one may conclude that the aerobic performance prediction of endurance athletes from $\dot{V}O_2max$, $v\dot{V}O_2max$, TE, RE and AT is dependent on the competition distance analyzed (1,500 x 5,000 m). However, the conduction of studies able to directly determine MLSS and also to analyze middle-distance competitions specialized athletes in order to verify the possible influences of these factors on data obtained in our study is recommended.

All the authors declared there is not any potential conflict of interests regarding this article.

REFERENCES

1. Denadai BS. Índices fisiológicos de avaliação aeróbia: conceitos e aplicações. Ribeirão Preto: BSD, 1999.
2. Caputo F, De Lucas RD, Mancini E, Denadai BS. Comparação de diferentes índices obtidos em testes de campo para predição da *performance* aeróbia de curta duração no ciclismo. Rev Bras Ciênc Mov 2001;9:13-7.
3. Denadai BS. Avaliação aeróbia: consumo máximo de oxigênio ou resposta do lactato sanguíneo? In: Denadai BS, editor. Avaliação aeróbia: determinação indireta da resposta do lactato sanguíneo. Rio Claro: Motrix, 2000;3-24.
4. Daniels JA. A physiologist's view of running economy. Med Sci Sports Exerc 1985;17:332-8.
5. Kiss MAPM. Potência e capacidade aeróbias: importância relativa em esporte, saúde e qualidade de vida. In: Amadio AC, Barbanti VJ, editores. A biodinâmica do movimento humano e suas relações interdisciplinares. São Paulo: Estação Liberdade, 2000;175-84.
6. Tanaka K, Matsuura Y, Matsuzaka A, Hirakoba K, Kumagai S, Sun SO, et al. A longitudinal assessment of anaerobic threshold and distance running performance. Med Sci Sports Exerc 1984;16:278-82.
7. Conley DL, Krahenbuhl GS. Running economy and distance running performance of highly trained athletes. Med Sci Sports Exerc 1980;12:357-60.
8. Billat V, Beillot J, Jan J, Rochcongar P, Carre F. Gender effect on the relationship of time limit at 100% $\dot{V}O_2max$ with other bioenergetic characteristics. Med Sci Sports Exerc 1996;28:1049-55.
9. Billat V. Interval training for performance: a scientific and empirical practice special recommendations for middle- and long-distance running. Part I: Aerobic interval training. Sports Med 2001;31:13-31.
10. Guedes DP. Controle do peso corporal: composição corporal, atividade física e nutrição. Londrina: Midiograf, 1998.
11. Jones AM, Doust JH. A 1% treadmill grade most accurately reflects the energetic cost of outdoor running. J Sport Sci 1996;14:321-7.
12. Billat V, Flechet B, Petit B, Muriaux G, Koralsztein JP. Interval training at $\dot{V}O_2max$: effects on aerobic performance and overtraining markers. Med Sci Sports Exerc 1999;3:156-63.
13. Heck H, Mader A, Hess G, Mucke S, Muller R, Hollmann W. Justification of the 4 mmol/l lactate threshold. Int J Sports Med 1985;6:117-30.
14. Daniels J, Daniels N. Running economy of elite male and elite female runners. Med Sci Sports Exerc 1992;24:483-9.
15. Faina M, Billat V, Squadrone R, De Angelis M, Koralsztein J.P, Dalmonte A. Anaerobic contribution to the time to exhaustion at minimal exercise intensity at which maximal oxygen uptake occurs in elite cyclists, kayakists and swimmers. Eur J Appl Physiol 1997;76:13-20.
16. Grant S, Craig I, Wilson J, Aitchison T. The relationship between 3 km running performance and selected physiological variables. J Sports Sci 1997;15:403-10.
17. Spencer MR, Gastin PB. Energy system contribution during 200- to 1500-m running in highly trained athletes. Medi Sci Sports Exerc 2001;33:157-62.
18. Billat V, Pinoteau J, Petit B, Renoux JC, Koralsztein P. Time to exhaustion at 100% of velocity at $\dot{V}O_2max$ and modeling of the relation time-limit/velocity in elite long distance runners. Eur J Appl Physiol 1994;69:271-3.
19. Billat VL, Morton RH, Blondel N, Berthoin S, Bocquet V, Koralsztein JP, et al. Oxygen kinetics and modeling of time to exhaustion whilst running at various velocities at maximal oxygen uptake Eur J Appl Physiol 2000;82:178-87.
20. Billat V, Sirvent P, Lepretre PM, Koralsztein JP. Training effect on performance, substrate balance and blood lactate concentration at maximal lactate steady state in master endurance-runners. Pflugers Arch 2004;447:875-83.
21. Ortiz MJ, Stella S, Mello MT, Denadai BS. Efeitos do treinamento de alta intensidade sobre a economia de corrida em corredores de endurance. Rev Bras Cienc Mov 2003;11:53-6.
22. Kohrt WM, O'Connor JS, Skinner JS. Longitudinal assessment of responses by triathletes to swimming, cycling, and running. Med Sci Sports Exerc 1989;21: 569-75.
23. Darrel PD, Costill DL, Fielding RA, Flynn MG, Kirwan JP. Effect of reduced training on muscular strength and endurance in competitive swimmers. Med Sci Sports Exerc 1987;21:569-75.
24. Paavolainen L, Hakkinen K, Hamalainen I, Nummela A, Rusko H. Explosive-strength training improves 5-km running time by improving running economy and muscular power. J Appl Physiol 1999;86:1527-33.
25. Jones AM, Doust JH. The validity of the lactate minimum test for determination of the maximal lactate steady state. Med Sci Sports Exerc 1998;30:1304-13.